Measuring growth of structure with intensity mapping data

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On the analysis of cosmological datasets

Two main pillars:

- Mock observations: testing estimators, foregrounds model, pipeline, etc…

  Challenging:

  $$V \simeq 5\,[\mathrm{Gpc}/h]^3,\ M_h \simeq \mathrm{few} \times 10^9\, M_\odot/h \longrightarrow N \simeq 20000^3$$

  Clearly not feasible in large numbers. Approximated methods, sampling, etc…

- A model: Perturbation theory, emulators, ML methods, etc...

  Unclear how good they work for IM.

Not obvious we would be ready to exploit IM potentials if foregrounds are solved for.

"I suppose I'll be the one to mention the elephant in the room."

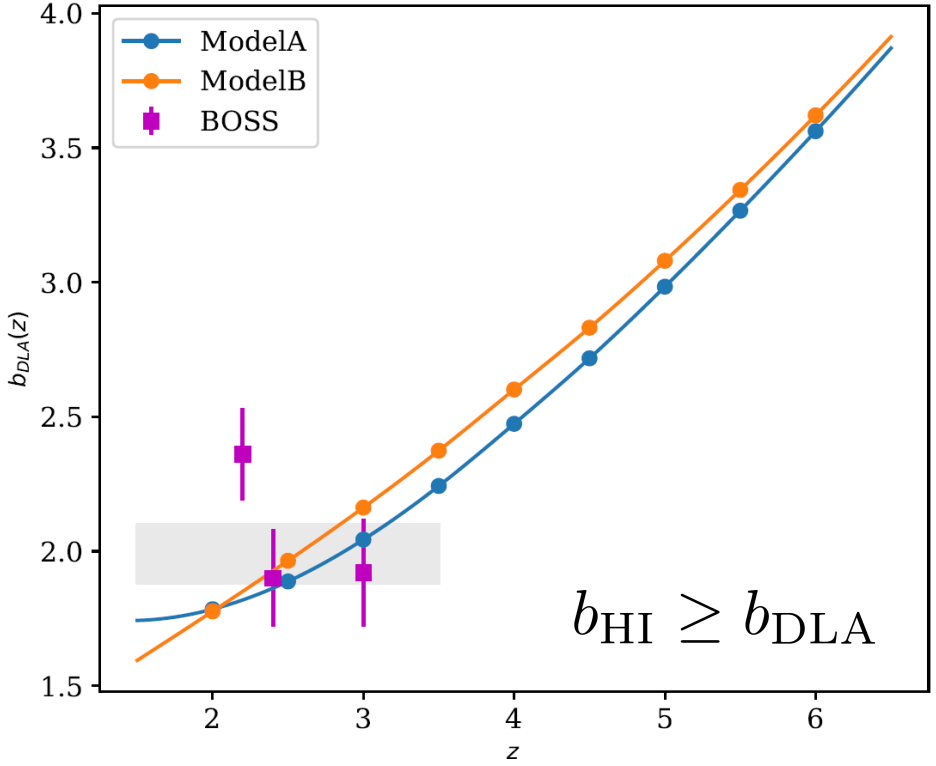
The Hidden Valley simulation suite

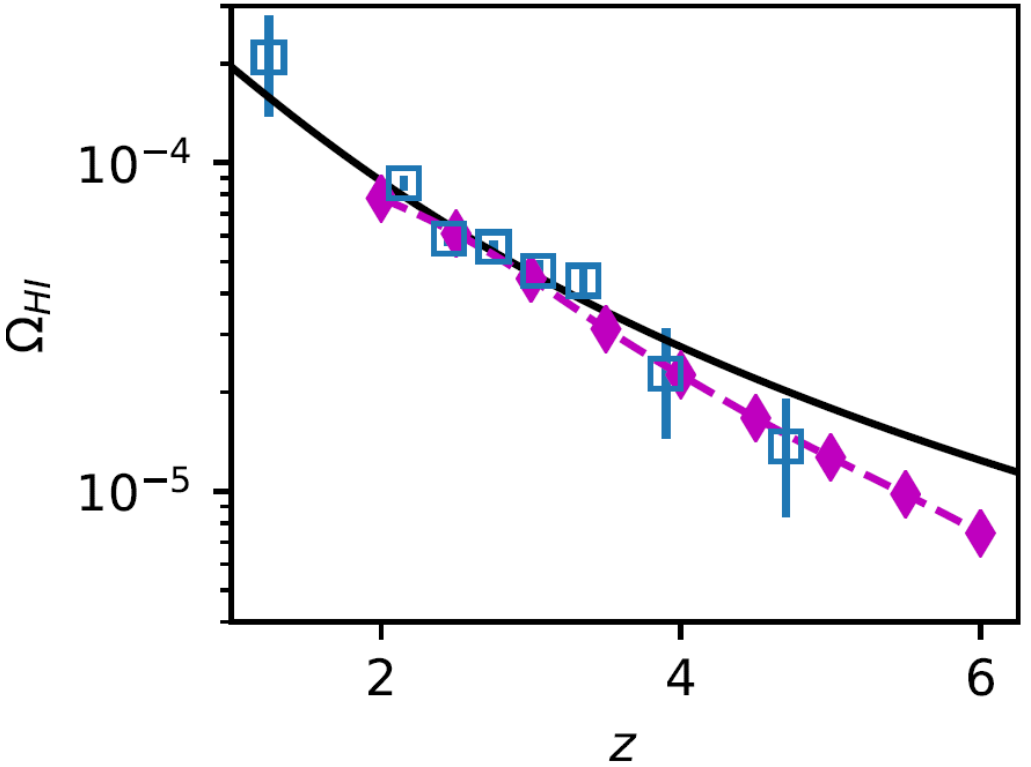
A good number of 8x10^7 M_sun/h resolution FastPM runs. <1% precision achieved on benchmarks compared to L=256 Mpc/h full gravitational physics run.

Facts: 9000 nodes and >500k MPI ranks, more than 90% of Cori at NERSC for the 10240^3 particles simulations. Runtime <1 hour. 100% credit to Yu Feng.

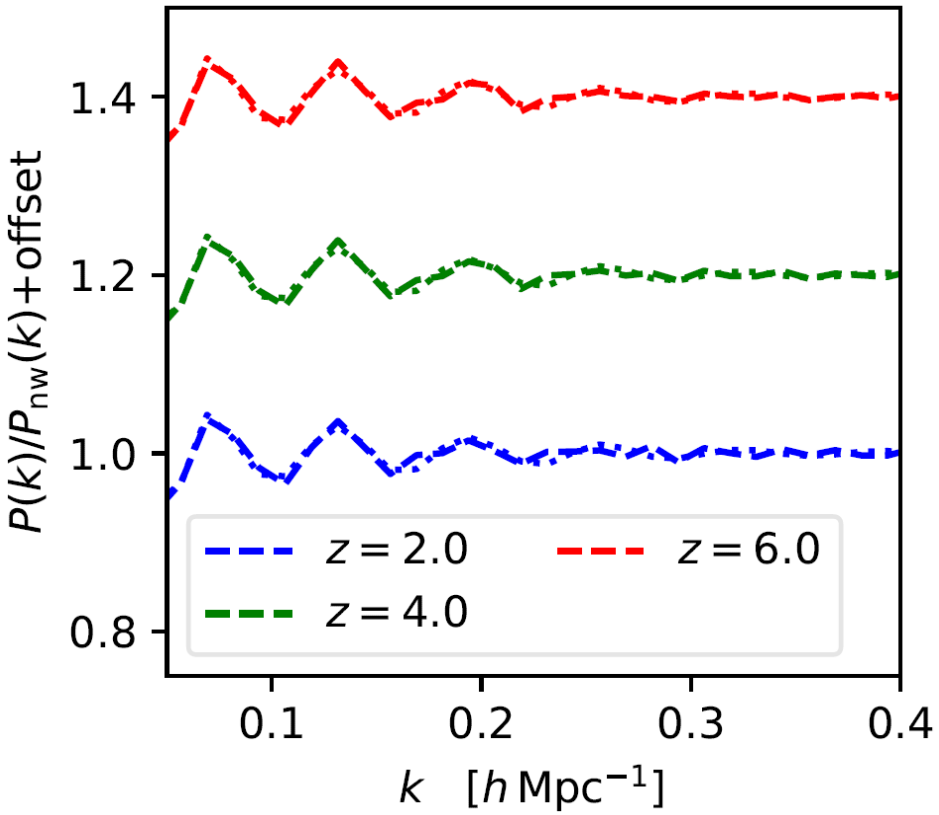
- Large volumes are required by BAO and RSD, not negotiable $V = 1\,[\mathrm{Gpc}/h]^3$

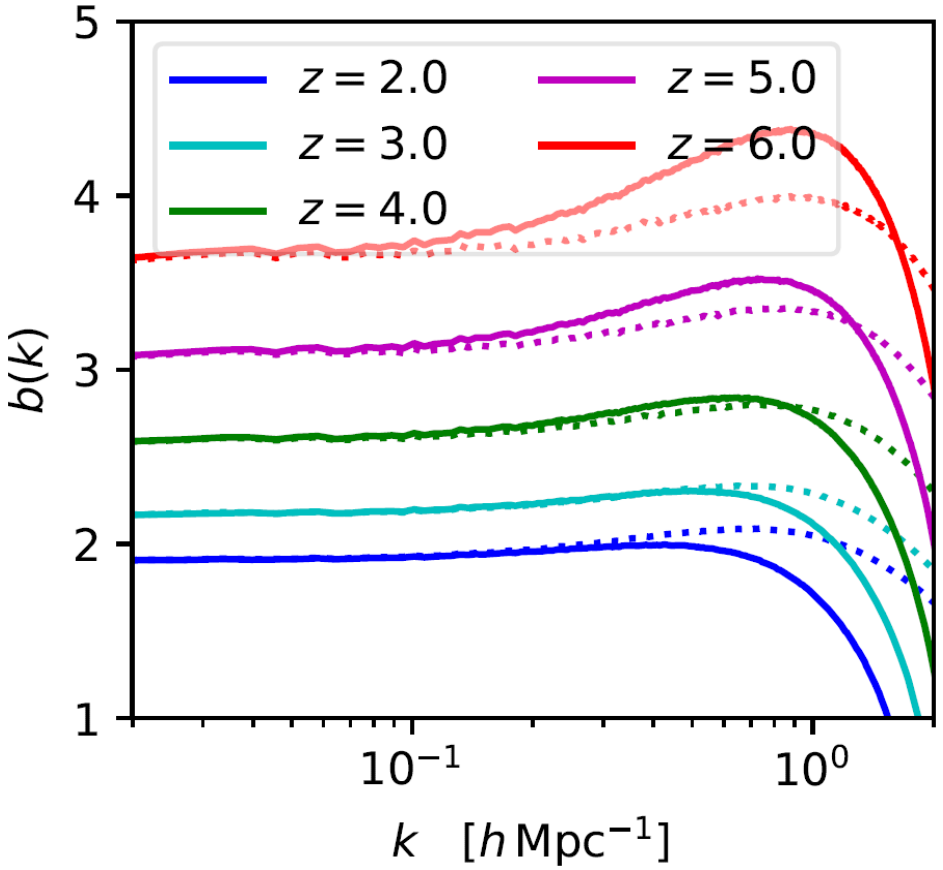
- Flexible! At z>1.5 the distribution of HI is 99% unknown. 4 HOD models.





Modeling observables at z>2





Disclaimer : numbers could be different in the real data !

Soon to be public. Useful for many other lines.

Modeling the signal

What we measure is

$$P_{21}(k,\mu) = \bar{T}_b^2[P_{\rm HI}(k,\mu) + P_{\rm sn}] + P_{\rm th}$$

In the linear regime it's impossible to constrain the amplitude of the power spectrum

$$P_{21}(k,\mu) = \bar{T}_b^2[(b_{\rm HI}\sigma_8 + f\sigma_8\mu^2)^2 P_m(k)/\sigma^2_{8,\,\rm fid} + P_{\rm sn}] + P_{\rm th}$$

Three possible ways out :

- External prior on brightness temperature. Hard to get better than 5 % (Obuljen, EC+)
- Cross correlations with QSOs, LBGs, etc. (Chan, EC+)
- Use information in the mildly non linear regime.

Modeling the signal

In the perturbative regime

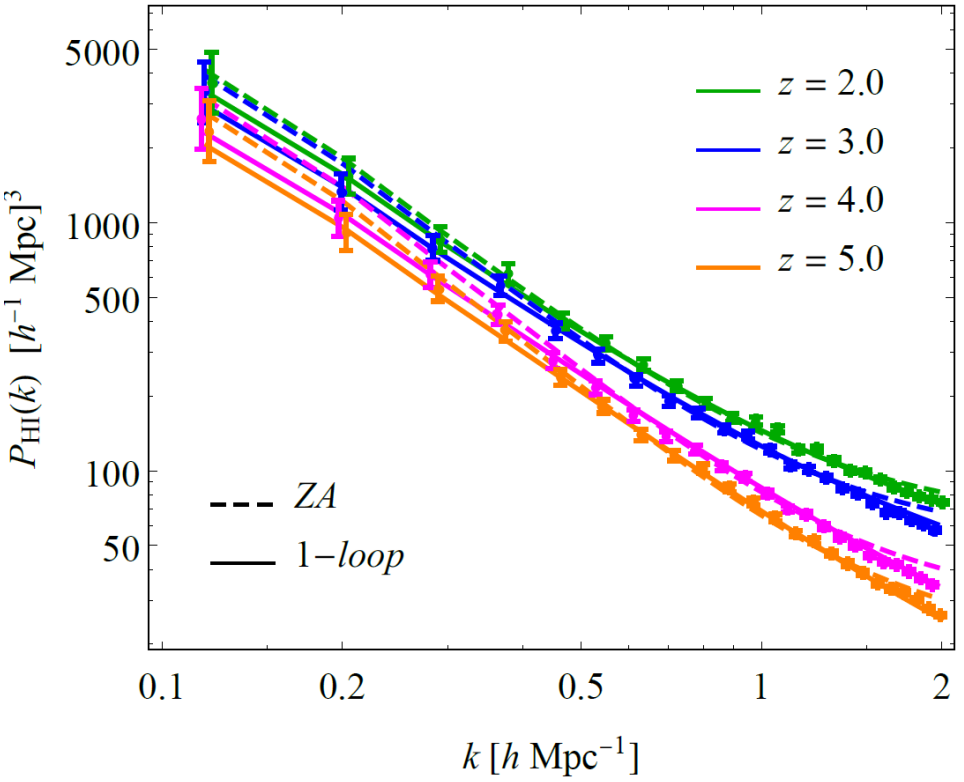
$$P_{21}(k,\mu) \simeq \bar{T}_b^2 P_{\rm HI}(k,\mu) = \bar{T}_b^2 [\mathcal{O}(P_L(k)) + \mathcal{O}(P_L(k)^2) + ...]$$

$f\sigma_8,\ (f\sigma_8)^2 \qquad (f\sigma_8)^2, (f\sigma_8)^3,\ (f\sigma_8)^4$

It turns out HI is the ideal tracer for PT: high-z, low mass halos, small satellite fraction

$$\begin{aligned} P_{{\rm HI},\ell}(k) = \bar{T}_b^2 \Big[& \left(1+\alpha_\ell k^2\right) P_{Z,\ell}(k) \\ & + b_1 P_{b_1,\ell}(k) + b_2 P_{b_2,\ell}(k) \\ & + b_1^2 P_{b_1^2,\ell}(k) + b_2^2 P_{b_2^2,\ell}(k) \\ & + b_1 b_2 P_{b_1 b_2,\ell}(k) \Big] \end{aligned}$$

Quite a good fit to the simulations!



Most scales are signal dominated

$$S = \bar{T}_b^2 P_{\rm HI}(k_{||}, k_\perp)$$

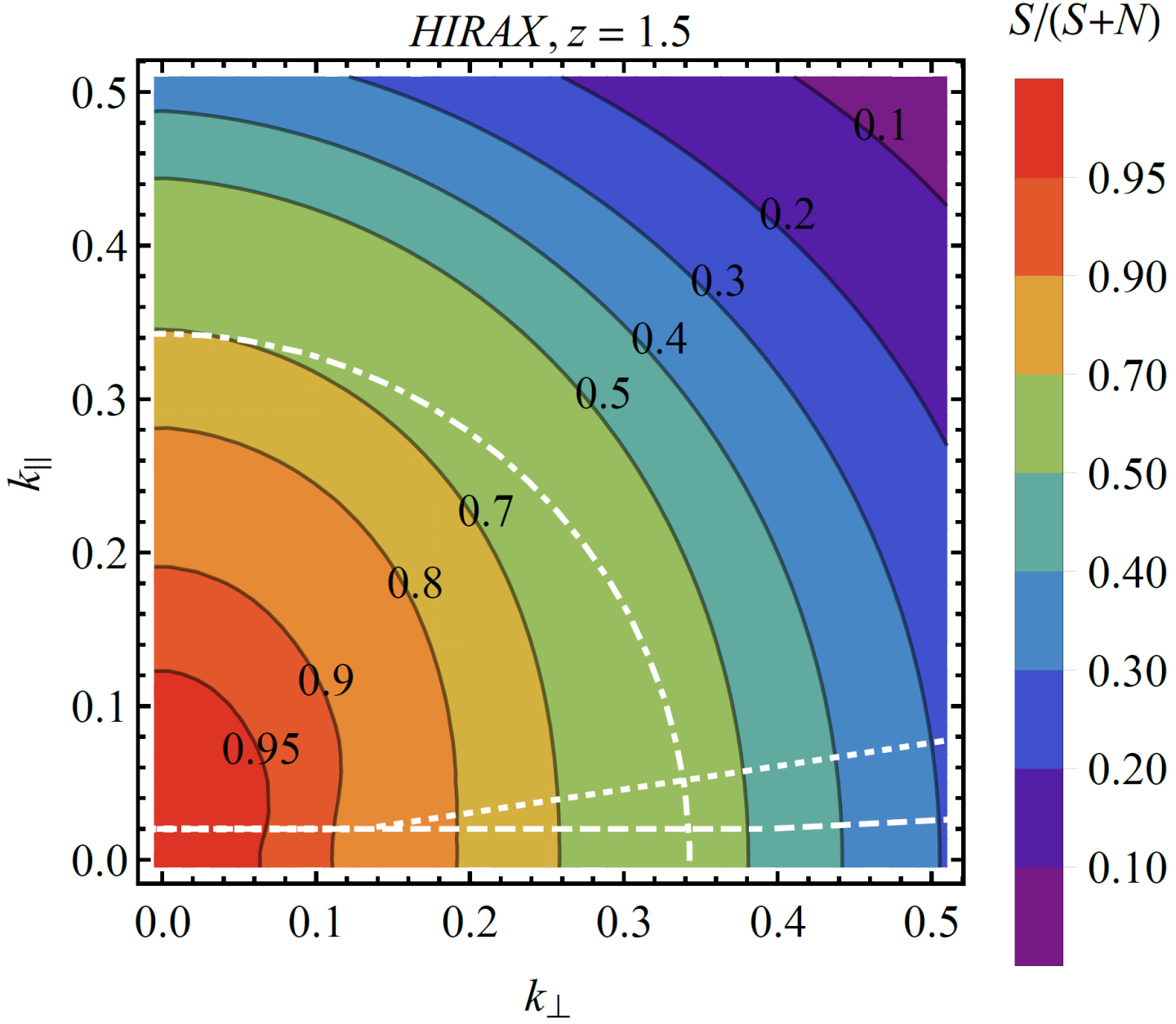
$$N = \bar{T}_b^2 P_{\rm sn} + P_{\rm th}(k_\perp)$$

All modes within the reach of PT are signal dominated.

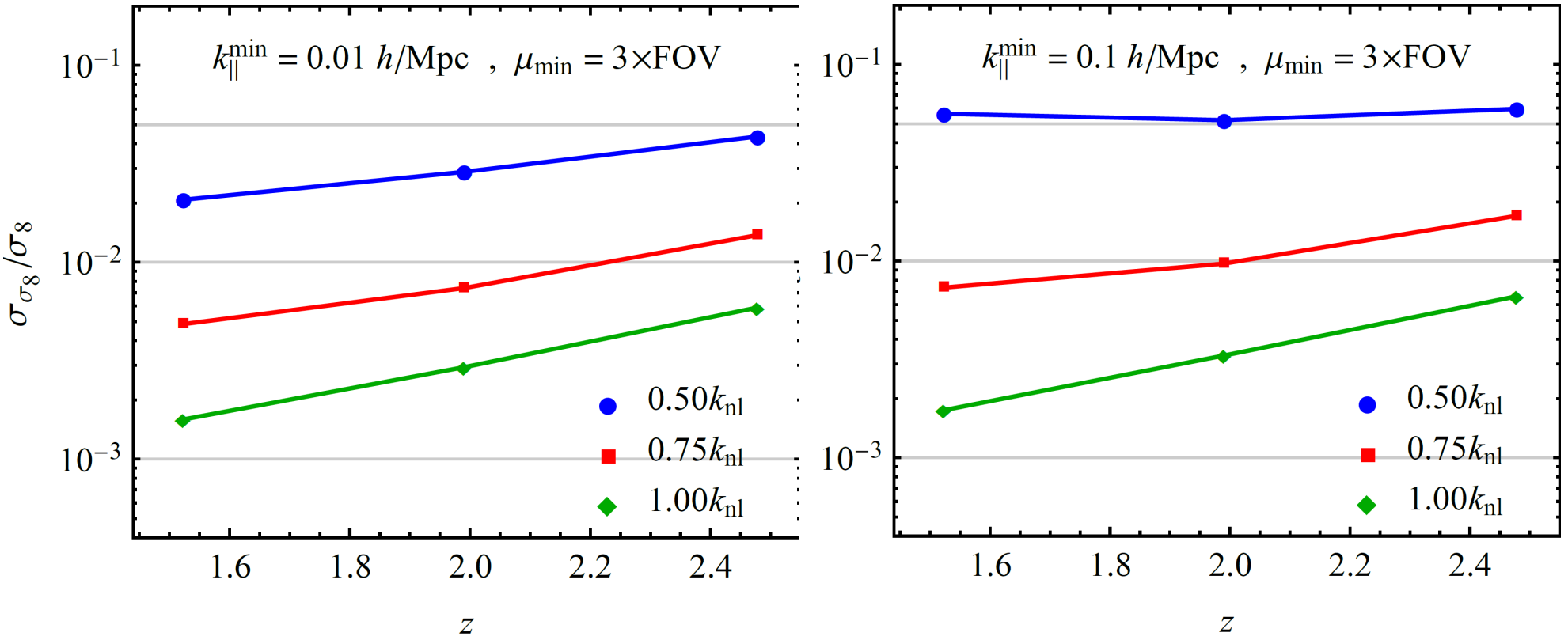
Not happening in galaxy surveys, unless you have ~1billion.

FoGs are very small.

3xFOV wedge does not kill too much signal. Horizon wedge does.



HIRAX performance



Sub- % measurement of growth of structure could be possible with HIRAX. Marginalized over bias parameters.

Unlikely with galaxy surveys at z>1.5.

Foregrounds can be overcome if we have a long enough lever arm.

Do not expect CHIME to land too far from HIRAX.

The Stage-II experiment

A 256x256, 6m arrray observing at 2<z<6.

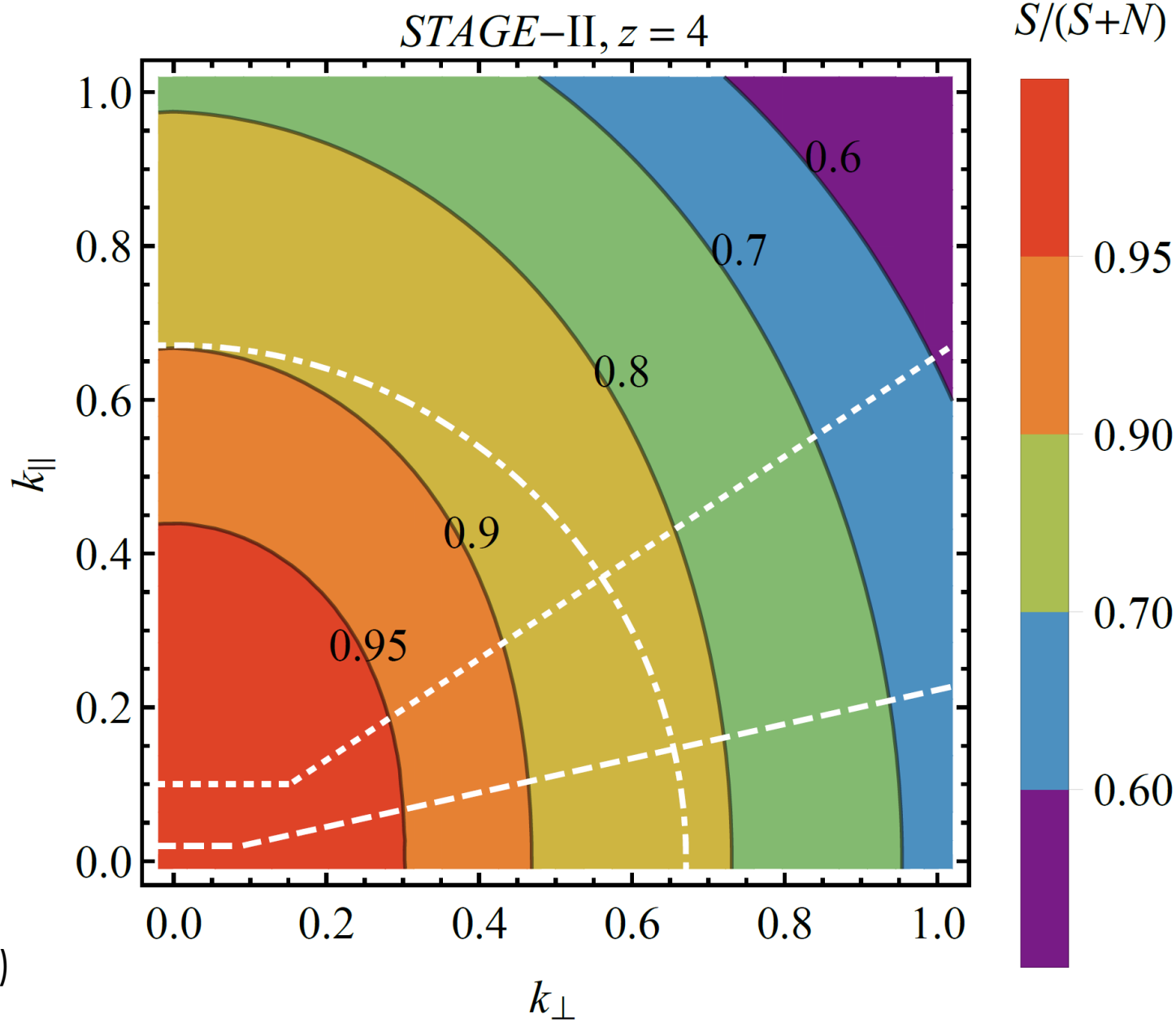
Final design TBD.

The ultimate post-reio cosmology survey.

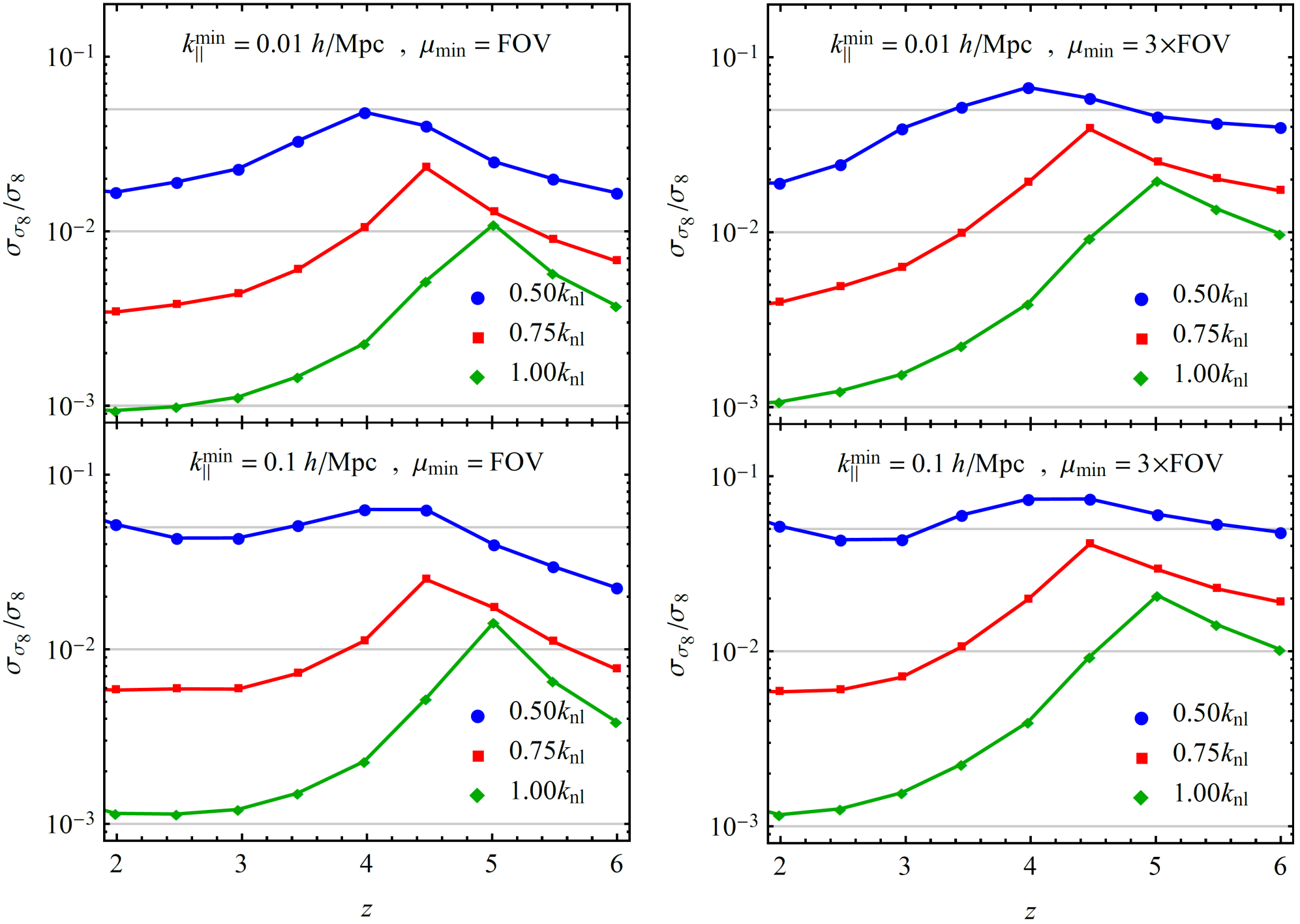
$$P_{\rm th} \leq P_{\rm sn} \ll P_{\rm HI}$$

Three main science goals :

- BAO and Dark Energy
- Primordial Non Gaussianities
- Primordial features in P(k)



≈1% measurements of growth of structure up to z<5



Conclusions

Large area IM experiments are also challenging from an analysis/theory perspective:

- How many light-cone mocks/simulations can we get away with?

  The Hidden Valley simulations is a first step towards realistic mocks at $z<6$.

- Use information in the mildly non linear regime to constrain growth of structure :

  - To the extent we do (not) know the HI distribution, PT works very accurately.

  - HIRAX is signal dominated over all perturbative scales at $z<2$.

    It could deliver sub- % measurement of growth of structure.

  - Work in progress on the final design of Stage-II 21cm experiment at $2<z<6$

    equivalent to ~10 billions galaxies survey : fNL and sub- % BAO and now RSD too.